IDENTIFICATION AND ANALYSIS OF AQUATIC AND RIPARIAN HABITAT IMPAIRMENT ASSOCIATED WITH HYDROMODIFICATIONS IN THE VIRGINIA COASTAL RESOURCES MANAGEMENT AREA

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30 April 2000

Proper Citation: McIninch, S.P. and G.C. Garman. 2001. Identification and analysis of aquatic and riparian habitat impairment associated with hydromodifications of the Virginia Coastal Resources Management Area. Final Project Report to Virginia Department of Conservation & Recreation, Richmond, VA.

This report was 55% funded by the Virginia Department of Conservation and Recreation in coordination with the National oceanic and Atmospheric Administration.

Summary

- Specific objectives for Phase II were 1) implement a process for the quantitative evaluation of potential habitat degradation associated with channelization and other hydromodifications, and 2) present recommendations on how to identify problems and potential opportunities for improvement of habitat.

- We examined 44 sites and measured habitat characteristics of a statistically valid number of tributaries in Coastal Resources Management Area, Virginia. In addition, a series of statistical analyses were performed to assess the quantitative and qualitative habitat variables collected in reference to hydromodification characteristics.

- The statistical approach of our study was designed 1) to identify potential degradations of habitat due to hydromodification, and 2) to compare variables with like systems under reference conditions.

- Results of the Canonical Correspondence Analysis do not show a clear separation of experimental and reference sites across the first two canonical axes for either channelized or dredging operations.

- Channelized streams and small dredged streams of the Coastal Resources Management Area do exhibit degraded conditions when compared to reference conditions. These differences are reflected in the overall habitat evaluation scores (Higher scores in reference conditions), but individually in few parameters.

- This study presents opportunities for restoration of instream habitats (specifically substrate and epifaunal cover), and riparian habitats (to aid restoration of reduced canopies).

Identification and Analysis of Aquatic and Riparian Habitat Impairment Associated with Dams of the Virginia Coastal Resources Management Area.

Introduction

Section 6217 of the reauthorized Coastal Zone Management Act (1990) contains provisions that require states with federally approved coastal resources management programs to develop coastal nonpoint source pollution control programs to address sources of Nonpoint Source (NPS) pollution, which degrade water quality of Coastal Plain tributaries. In 1993, a guidance document was released by the U.S. Environmental Protection Agency (EPA) to assist in developing nonpoint source pollution control programs [Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters, EPA-840-B-92-001c]. The Commonwealth of Virginia responded to the federal mandate by developing the <u>Coastal Nonpoint Source Pollution Control Program Submittal</u> [Department of Conservation & Recreation, September 1995]. The National Oceanic and Atmospheric Administration (NOAA) and EPA reviewed the control program and released findings in July 1998. Most recently, the Commonwealth of Virginia has completed the Nonpoint Source Pollution Management Program [Department of Conservation & Recreation, December 1999]. One potential source of nonpoint source pollution addressed in all of these documents is that produced by hydromodification.

Hydromodification includes channelization and channel modification, dams, and streambank and shoreline erosion. Generally, there are three potential sources of nonpoint pollution and habitat impairment under this heading: 1) dams, both new construction and existing structures, 2) excessive surface water withdrawals associated with existing dams, and 3) dredging and channel modification activities. The NOAA and EPA findings identified a few management areas where the Virginia program may be deficient, according to Section 6217 (g) guidance. "Virginia's program does not include: (1) a process to improve surface water quality and restore instream and riparian habitat through the operation and maintenance of existing modified channels; (2) management measures to manage the operation of dams to protect surface water quality and instream and riparian habitat and to assess nonpoint source problems resulting from excessive surface water withdrawals; (3) management measures for chemical control at dams; and (4) a process to identify and develop strategies to solve existing nonpoint source problems caused by streambank or shoreline erosion that do not come up for review under existing permit authorities." These issues are mostly concerned with existing structures but DCR presently lacks a system for the identification and assessment of potential problems (i.e. habitat impairment) associated with hydromodification activities.

The goal of this study is to investigate the many forms of hydromodification in the Coastal Resources Management Area and examine their impact on instream and riparian habitats. The initial research (Phase I) focused on the most prominent hydromodification in the Coastal Resources Management Area, dams. An accurate and comprehensive database for dams in the Coastal Resources Management Area of Virginia was compiled and an evaluation of potential habitat degradation below these existing dams was made (see McIninch and Garman 2000 report). A similar quantitative evaluation of potential habitat degradation below other hydromodification types is reported herein and constitutes Phase II of this ongoing research. A proposed Phase III will finalize the analysis of habitat impairment associated with

hydromodification types by examining channel modifications of larger rivers (i.e. James River mainstem) mostly in the form of dredging operations.
OBJECTIVES

The specific objectives of the Phase II study were:

1. **Compile a listing of hydromodifications, save dams, in the Coastal Resources Management Area of Virginia**
2. **Examine the Literature for potential habitat problems associated with channelization and other hydromodification types.**
3. **Develop and implement a process for the quantitative evaluation of potential habitat degradation below these hydromodifications.**
4. **Present recommendations on how to identify problems and potential opportunities for improvement of habitat.**

METHODS

Project Approach

The approach for the second phase study was a replicate of Phase I (see McIninch and Garman 2000). In brief, we performed a literature search to examine known and potential affects of hydromodofications on streams, their habitats, and their riparian corridors. Next we sought out databases from which to pick study sites from the Coastal Resources Management Area of Virginia. These sites were to be chosen to reflect Coastal Resources Management Area hydromodification excluding large river dredging operations (proposed for examination in Phase III). Chosen sites were examined for a group of habitat parameters and compared with a nearby system representing a least impacted (or reference) condition. Following data collection, records were analyzed for variability, correlation, and effects of the examined hydromodifications.

A major difference with that of Phase I was the size and clarity of the database from which to glean study sites. In comparison to records in existence for dams on water of the Coastal Resources Management Area of Virginia, records for other hydromodifications, such as small stream channelization are scarce. Numerous contacts with regulatory agencies including VMRC (chief regulating authority; site VA Code)), DEQ, and US Army Corp of Engineers located only a handful of small stream hydromodifications for the study region. Records of hydromodifications from VMRC are separated into two categories for our purposes; 1) non-permitted applications where modifications were such that no permit was necessary and 2) permitted files that included those hydromodifications performed in the Coastal Resources Management Area after a permit was issued. Group 1 included those hydromodifications in man-made habitats. The large majority of these records because they were in man-made canals and ponds were deemed unfit as study sites for the present study. The second group of files (those requiring permits) is composed mostly of small dredge operations, and pier and bulkhead development. Many of these records that are located on large coastal areas (such as beach replenishment and fish piers) were excluded from consideration. Permit required for sand mining were listed in the second group of files but are very limited in number for the Coastal Zone

Management Area. The large majority of sand mining operations in the state occur in the Dan River system (Albemarle Sound drainage). Old records of small stream channelization in the state could not be located. Discussions with landowners in portions of Virginia's Coastal Resources Management Area suggests that much of the agricultural ditching and stream straightening (channelization) was done many years ago (prior to 1970) and that permits (hence paperwork) was not required.

We used a random number program to pick sites from the permitted list of files. Following the random number generation, VMRC personnel pulled the selected files and we examined them for information on type of hydromodification, date of modification, location, etc. Four sets of 30 picks were examined prior to finding the ten examined sites. Sites were excluded if they were primarily dredging operations, took place in large coastal areas, involved road construction or were out of the Coastal Zone Management Area (sand mining). Because these sites included no stream channelization projects we chose two to three channelized streams for each major watershed (Potomac, Rappahannock, York, James) and an additional 2 from the Eastern Shore where agricultural ditching is widespread. For each channelized stream chosen we attempted to locate a nearby stream section, preferably in the same stream, to serve as a reference condition. A total of twenty-four sites were assessed for channelization effects and an additional 20 were assessed for other hydromodification types. All sites evaluated on-site for the status of each hydromodification, the specific location coordinates, pertinent characteristics (e.g. condition, size, type, etc.), and photographed (Table 1). Location coordinates were established using a Trimble GPS unit and post processed using Geo Explorer software and the assistance and base files of Harry Berquist (College of William & Mary, Virginia Institute of Marine Science).

Habitat assessment

Through quantitative habitat analysis, we developed a database that allowed for the scientific evaluation of specific impairments of stream habitats. Selected habitat attributes were directly or indirectly related to the quality of fish and wildlife habitat in those areas below hydromodifications. The purpose was to identify specific habitat impairments that may be associated with one or more types of hydromodification and to quantify the degree of such impairments. Those identified impairments were then scrutinized in order to identify opportunities for habitat restoration.

A power analysis (Link and Hatfield 1990, Cohen 1988) was used to estimate the number of study sites needed to obtain a statistically valid sample of sites to assess variable habitat conditions. The analysis suggested 28 samples would be sufficient. We were able to find 22 experimental sites and included 20 reference (control) sites for comparative purposes. Reference streams were selected to correspond to streams of similar size and placement in the watershed as those streams examined (study sites). The final 44 study sites are representative of the various categories of hydromodifications (except dams and large river dredging operations) in Coastal Resources Management Area tributaries of Virginia (Table 1).

Site visits were made during the period November 2000 – December 2001. Habitat variables examined included physiographic parameters (e.g. stream order; link magnitude measures), physico-chemical parameters (e.g. pH; conductivity, temperature, turbidity, channel dimensions; flow characteristics), structural attributes (e.g. substrate composition; large woody debris) and assessment of riparian habitat and stream cover. The habitat assessment protocol followed EPA's rapid habitat assessment protocol (Barbour et al. 1999; Appendix I). In addition to the rapid assessment sheets used (Fig. 1), we also assessed/measured physical habitat and water quality parameters of the stream (Fig. 2).

Physiographic parameters were determined using 7.5-minute topographic maps and ESRI ArcView (ver. 3.1) software. Water quality measures such as pH and dissolved oxygen were measured on-site using calibrated meters. Turbidity was measured using a Texas Instruments Nephelometric turbidimeter and flow was measured using a Marsh-McBirney current meter. In areas of tidal influence, flow was not measured. Width and depth characteristics of wadable streams were measured at three points corresponding roughly to transects at 25 m, 50 m, and 100 m below the dam. We estimated visually the substrate type and cover over the reach of the stream that was assessed for habitat conditions.

Data Analysis

Statistical analyses were performed using SPSS® and CANOCO® software. All habitat data was examined initially for outliers and normalcy of distribution. Normalcy was tested using the Kolmogorov-Smirnov Test (SPSS®). Outliers were examined for accuracy and those variables not exhibiting normal distributions were transformed using appropriate transformations for linear analysis. Data for percentages of habitat parameters in the habitat database was transformed using an arc-sine transformation (Sokal and Rohlf 1987).

Following descriptive statistical analysis, the data were subjected to a series of direct gradient analyses (Canonical Correspondence Analysis; CCA) to explore the relationship, if any, between habitat information collected at impounded and reference sites. Canonical correspondence analysis was used to ordinate the data into two dimensions while concurrently executing a multiple regression analyses of the habitat characteristics (Jongman et al. 1988, Ter Braak 1988).

We used the CCA analysis to examine how sites ordinated along the environmental gradients (habitat variables) tested. The null hypothesis was that there is no grouping(s) of sites within the Coastal Resources Management Area of Virginia. These analyses supply information about how a range of stream sites are grouped within the Coastal Resources Management Area and allow an initial insight into potential relations with the environmental variables examined. A Monte Carlo test was executed to test the statistical significance of the first resultant axis from the CCA (Ter Braak 1988). We used a null model and 99 iterations of the Monte Carlo examination. Level of significance was set at 0.01 for the Monte Carlo test; for all other statistical analyses the level was 0.05.

Additionally, independent t-tests were performed on the habitat dataset. Levene's test for equality of variances was used to assess variances between the experimental group (modified streams) and control group (reference streams); habitat variables not meeting the assumptions of normality or showing unequal variance between groups were subjected to Mann-Whitney tests (George and Mallery 1999). Remaining variables were analyzed to assess differences in habitat components between the experimental and control groups using the t-test for equality of means.

Hydromodifications of Virginia's Coastal Resources Management Area

Phase I of the hydromodification study identified and analyzed habitat impairment associated with dams of Virginia's coastal resources management area (CRMA). Dams, however, are but a single type of hydromodification. Other major hydromodifications include dredging operations, primarily for the maintenance of navigation channels, and other channel modifications (or channelization). Channelization projects are ubiquitous with about one-quarter million miles of the country's waterways being channelized between 1820 and the early 1970's (Schoof 1980). The extent of channelization varies greatly from small ditched agricultural streams that aid in irrigation to large mainstem projects for the purpose of navigation and flood control. The one thing all channel modifications have in common is that man engineers them. Streams and rivers are channelized for the purpose of flood control, navigation, drainage improvement (including wetland draining), and reduction of channel migration potential (Nunnally 1978; Brookes 1988, 1990). In the process streams are enlarged, straightened, deepened, embanked, or relocated. These hydromodifications usually result in more uniform channel cross sections, reduced average depths (especially in pools) and steeper stream gradients. The benefits of channel modification has often been at the expense of biotic health and diversity (White 1980, Schlosser 1981, Jackson, 1989), and have great potential to impact ecosystems (Ward 1998). Some of the potential impacts reported in the literature are given below.

The straightening, widening, and deepening associated with most channelization projects generally results in an increase in the flow and velocity of flow through the altered channel. This alteration of flow 1) results in increased erosional capacity; 2) directly disrupts the stream ability to retain fine sediments and vegetation and 3) commonly results in downcutting of the channel. The resulting impact on the instream habitat may include erosion of stream banks, creation of an armored streambed, higher turbidities, and lowered heterogeneity of habitat types. Additional impacts that may occur outside of the immediate area include 1) sediment deposition further downstream when velocities decrease, 2) upstream downcutting of the streambed due to increase slope and velocity, 3) loss of connection with the flood plain and riparian areas (Nunnally and Keller 1979, Anderson and Omhart 1985, Herricks and Osborne 1985, Shirmohammadi, Sheridan and Asmussen 1986, Simon 1989). Clearing of stream and rivers, commonly through dredging, also results in increases in flow with reduced roughness of streambed. This often has similar results to channelization.

Biotically, channelized streams have been found to support tolerant macroinvertebrate faunas at the expense of rare and intolerant forms (White 1980). Fishes, as well as macroinvertebrates, are commonly reduced in both numbers and diversity because of reduced habitat heterogeniety and decreased water quality (Schoof 1980, Schlosser 1981 and citations therein, Brookes 1988, Crispin 1993). The loss of connection to the flood plain (required for life stages in some taxa) and reduced recolonization potential also play a role in reduced biotic communities in channelized streams.

The extent of erosion to the stream banks and degradation of streambeds is dependent on the composite material and geomorphic placement of individual streams. For this reason, much of the literature reporting channelization effects has questionable merit in coastal plain environments. For example, an Oregon trout stream will likely differ in the type of stream channelized as well the reaction to channelization that one in Virginia Coastal Plain. Gradient, slope and bed materials are of great importance. What seems to be of importance is the equilibrium or quasi-equilibrium that a system (stream, channel, and ecosystem) attempts to maintain. This equilibrium dictates that the stream size, shape and slope are generally attuned to the amount and variation of discharge and the supply of sediments (Simon 1989). In this sense, a stream with an armored streambed or incised bed, undercut banks, washed out riffles or filled in pool habitats would not be indicative of a stream in dynamic equilibrium with its flow (Nunnally and Keller 1979). The status of equilibrium or dynamic equilibrium in the streams of Virginia coastal zone management area requires further study. For this study we have attempted to examine the habitat impairment associated with stream channelization and other minor dredging hydromodifications.

Results

Habitat Assessment

Study sites selected and reference streams examined are listed in Table 1. Statistical analyses were performed separately on channelized streams and those impacted by minor dredging and other hydromodifications.

Channelized Streams

Results of the Canonical Correspondence Analysis did not show a clear separation of sites across the first two canonical axes. The first axis was not statistically significant (P=0.57; Monte Carlo simulation. These results indicate that there was no clear separation among those sites examined in regards to those habitat variables measured.

Figures 3-5 are plots of the first two canonical axes resulting from the canonical correspondence analysis. The first letter of the site code is either C (for channelized stream) or R (for reference stream). The following three letters represent the drainage and the numbers correspond to those sites listed in Table 1. Note that all sites or environmental parameters could not fit on the plots due to printing abilities.

Figure 3 is a standard plot of the ordination of the sites based on the environmental data. The sites have been classified as channelized or reference streams and separate symbols given. Figure 4 is the plot of the environmental data of significance. Vectors represent continuous data and the diamond symbols represent the landuse variables listed. The final figure (Fig. 5) shows a plot with both sites and environmental variables listed. The first horizontal axis represents a gradient (moving right to left as one looks at the plot) of stream velocities and landuse parameters (Fig. 4, Table 2). Positive correlations (right side of plot) were found only with velocity. Negative correlations (left side of plot) were highest with variables describing landuse as either Forested, Wetland, or both (Table 2).

The second axis is the vertical axis and represents a gradient (moving top to bottom as one looks at the plot) of mostly landuse parameters separating positively correlated (upper portion of plot) agricultural landuse with high measurements of turbidity (NTU) and negatively correlated forested wetlands and deeper water (Table 2). Those sites located toward the origin (center of the plot) indicate no strong alignment with any of the environmental variables tested.

These data do not exhibit a clear separation between reference and experimental groups or based on the attributes used to analyze the channelized streams.

The next step in our data analysis was to perform more direct, and powerful, examinations of potential difference between experimental and control groups. Results of the independent-samples t-tests, and nonparametric (Mann-Whitney, Kruskal-Wallis) analyses are presented in Tables 3.

There was a statistically significant difference between the total habitat evaluation scores of experimental and reference sites (P=0.025). Each of the rapid habitat assessment parameters was next analyzed individually. Those metrics that showed significant differences between experimental and reference sites include the amount of available cover available as epifaunal substrate (P=0.02), the extent of channel alteration (P=0.001), and the extent of sinuosity of the stream (P=0.02; Table 3).

The analysis of additional habitat parameters including those representing instream morphological features (amount of riffle, run and pool habitat), water quality parameters and substrate composition attributes are listed in Table 3. None of the water quality parameters measured (temperature, turbidity, pH, dissolved oxygen, and conductivity) were significantly different between experimental and control sites. Likewise, flow velocity, stream depth and stream width were the same between the two groups of streams. Unexpectedly, the proportions of riffle, run and pool habitat did not differ between experimental and control sites. Substrate composition exhibited significant differences between experimental and control groups, but only for the amount of sand substrate (P=0.03). The extent of canopy over the stream exhibited a significant difference between experimental and references streams (P=0.02; Table 3).

Small scale Dredging Operations

Results of the Canonical Correspondence Analysis indicate a clear separation among those sites examined based on the habitat variables measured. There was no clear separation of reference versus control sites. However, the first axis was statistically significant (P=0.01; Monte Carlo simulation) indicating significant variation in variables.

Figures 6-8 are plots of the first two canonical axes resulting from the canonical correspondence analysis. The first letter of the site code is either a number referring to the site number or C (for control stream) followed by the last five numbers of the corresponding dredged site number (Table 1). Note that all sites or environmental parameters could not fit on the plots due to printing abilities.

Figure 6 is a standard plot of the ordination of the sites based on the environmental data. The sites have been classified as dredged or reference streams and separate symbols given. Figure 7 is the plot of the environmental data of significance. Vectors represent continuous data and the diamond symbols represent the landuse variables listed. The final figure (Fig. 8) shows a plot with both sites and environmental variables listed.

The first horizontal axis represents a gradient (moving right to left as one looks at the plot) of landuse parameters and some stream morphometrics (Fig. 7, Table 4). Positive correlation (right side of plot) was found with a predominance of agricultural landuse and link metrics indicating higher positions in the watershed. Negative correlation (left side of plot) was highest with measurements of turbidity and deeper streams (Table 4).

The second axis is the vertical axis and represents a gradient (moving top to bottom as one looks at the plot) of both landuse parameters and some water quality measurements. Positive correlation (upper portion of plot) was strongest with dissolved oxygen concentrations and to a lesser extent with landuse variables indicating wetland or marsh type. Negatively correlated variables include stream width, depth and turbidity (Table 4). Those sites located toward the origin (center of the plot) indicate no strong alignment with any of the environmental variables tested. Although there is separation of sites in the ordination, these data do not exhibit a clear separation between reference and experimental groups.

To directly examine variation between dredged and reference sites, our next procedure included independent-samples t-tests, and nonparametric (Mann-Whitney, Kruskal-Wallis) analyses. Results are presented in Table 5.

The first analysis examined differences in compiled scores from the rapid habitat assessment protocol. There was a statistically significant difference between experimental and reference sites (P=0.004). Each of the rapid habitat assessment parameters was next analyzed individually. Those metrics that showed significant differences between experimental and reference sites include the amount of available cover available as epifaunal substrate (P=0.02), the extent of channel alteration (P=0.04), the degree of bank stability (P=0.03) and the width of the riparian zone (P=0.02; Table 5).

The analysis of additional habitat parameters including those representing instream morphological features (amount of riffle, run and pool habitat), water quality parameters, and substrate composition attributes are listed in Table 5. None of the water quality parameters measured (temperature, turbidity, pH, dissolved oxygen, and conductivity) were significantly different between experimental and control sites. Likewise, flow velocity, stream depth and stream width were the same between the two groups of streams. The proportions of riffle, run and pool habitat did not differ between experimental and control sites and no substrate composition differences were noted. Likewise, the extent of canopy over the stream exhibited no significant difference between experimental and references streams (Table 5).

Discussion and Recommendations

Instream and riparian habitats were assessed from areas in and around hydromodifications including channelization projects and projects including small-scale dredging operations. All sites were located within the Coastal Resources Management Area of Virginia. We used the U.S. Environmental Protection Agency's Rapid Habitat Assessment protocol as one form of habitat evaluation. Additional quantitative habitat information on substrate, stream morphometry, and water quality was collected. These data were subjected to exploratory analyses in the form of direct gradient analyses and then to more direct comparative analyses using independent samples t-tests and nonparametric analyses where necessary.

The statistical approach of our study was designed 1) to identify potential degradation of habitat due to hydromodifications, and 2) to determine if certain habitat attributes could be linked to a specific type of degradation. The channelized streams of the Coastal Resources Management Area exhibit degraded conditions when compared to those reference streams examined. These differences are reflected in the overall habitat evaluation scores (Higher scores in reference conditions), but individually in few parameters. Of the parameters evaluated only five could be shown to be significantly different than like reference streams.

Three of these five significant parameters in part define channelization. The first (stream alteration) is described as the extent to which the stream in question has been altered or modified (Barbour et al. 1999). The second parameter (sinuosity) is also obviously reduced with channelization as the stream is most often straightened. The third significant parameter is percent of stream coverage by the riparian canopy. Most of the immediate riparian vegetation is most likely removed during channelization and degrees of grow-back vary with landuse. The remaining two significant parameters detail the extent of substrate as sand and the extent of epifaunal cover (a measure of habitat heterogeneity). In general, channelization increases flow through a more direct channel and therefore often significantly alters sediments by removing silt and other easily moved particles. This may include sand in areas of higher gradient but is not likely the case in Coastal Plain streams where gradients are low. The straightening of the stream channel generally reduces the amount of substrate available for epifaunal colonization by reducing roughness of stream bottom (through removal of woody debris and other potential habitat (rocks, boulders) and by removing stream bends where pool development, undercutting of some banks, and exposed vegetation roots often supply variable habitat types in coastal plain streams and rivers. The statistically significant difference of the parameter between control and channelized conditions suggest that this problem is enduring.

Similar to results of the channelization analyses, those sites representing small-scale dredging operations exhibited an overall significant difference with rapid habitat scores but few when the individual parameters where examined. Emulating the channelization results, the extent of epifaunal cover and stream alteration were found to be significantly different from reference conditions in those streams impacted by dredging operations. Again, because dredging operations often remove sediments, large woody debris, and other structures, the overall habitat heterogeneity of the system will be reduced by the hydromodification. In the case of stream alteration, many of the small scale dredging operation sites involved not only dredging but bank alteration in the way of piers, boat ramps, and bulkheads. The presence of these items constitutes a stream alteration and thus an impact on the stream.

The stability of the stream bank and the extent of riparian vegetation on the stream bank where assessed and analyzed for both banks individually. The results indicate a weak but significant difference for both of these variables for only one of the two banks examined and thus may be due to other factors (i.e. landuse).

Hydromodifications in the form of channelization and small-scale dredging operations have had some lasting impacts on habitat in the Coastal Resources Management Area of Virginia. The degree of impacts however requires further study. In addition to those few parameters found to be different in altered versus reference streams there were many that exhibited no significant differences. Interestingly, channelized streams exhibited lesser values for canopies. This is often considered degradation in water quality due to the increases in stream temperature associated with reduced canopies. However, temperature was not found to be significantly different between experimental and reference conditions in this study. Similarly, hydromodifications often results in an increase in the flow and velocity of flow through the altered channel. The consequences of this are mostly increased erosional capacity, disruption of the ability to retain fine sediments and downcutting of the channel. We did not document grand erosion of stream banks, higher turbidities, armored streambeds or differences in stream depths or downcutting. A potential explanation for these enigmatic findings is that stream systems and their associated habitats react differently in Coastal Plain environments. We do not expect great increases in stream velocity and flow because there is insufficient gradient to create great alterations in flow. Likewise, sediments of the coastal plain are commonly being shifted about because they consist mostly of the finer alluvial sediments; gravel, cobble, and bedrock substrates are rare.

A difficulty in assessing hydromodifications and the associated impact on stream habitat is the clear association with other potential habitat altering variables. For example, certain landuse situations may result in habitat effects similar to those commonly associated with hydromodifications. Increases in turbidity and siltation can easily arise from agricultural landuse (i.e. cattle grazing) in both channelized and reference streams. The extent of habitat recovery over time is another difficulty due to potential outside variables. Low gradient streams that have naturally varying water quality attributes characterize the coastal zone. The amount and characteristics/quality of the water depends on groundwater sources and on the relationship of the stream with the flood plain. The loss of connection to the flood plain (required for life stages in some macroinvertebrate and vertebrate taxa) and reduced recolonization potential have been found to play a role in reduced biotic communities in channelized streams White 1980, Schoof 1980). This interconnectiveness was not examined in the present study but may play an important role in coastal plain environments.

The habitat parameters found to be significantly different from reference conditions are similar in both the case of channelized streams and those impacted by small-scale dredging operations. Although the stream alteration will not likely be corrected without major stream restoration activities, other parameters may present themselves as opportunities for restoration activity. The two most important and manageable variables are the extent of instream cover and the extent of the riparian zone. Management practices to aid/restore **riparian** vegetation will help the canopy restoration. At the same time, is likely to increase woody debris and subsequently instream habitat. Instream restoration of large habitat structure would also be beneficial for aquatic faunas.

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Table 1. Final study sites for Phase II of hydromodification study.

Id No.	Stream	Location	Drainage
		Channelization Sites	
Cpot1	Potomac Creek	Co Rte 625, Stafford Co.	Potomac
Cyor1	Maracossic Cr	Co. Rte 640; Caroline Co.	York
Cjam1	White Oak Swamp	Co. Beaulah Rd; Henrico Co.	James
Crap1	Hazel Run	Rte2/17; Spotsylvania Co.	Rappahannock
Cyor2	Stevens Mill Run	Rte 1; Caroline Co.	York
Cpot2	Unnamed trib Aquia	Co Rte 687; Stafford Co.	Potomac
Crap2	Dragon Run	Co Rte 604; King & Queen Co.	Rappahannock
Crap3	Totuskey Cr	Rte 3; Richmond Co.	Rappahannock
Cjam2	Toe Ink Cr.	Rte 60; New Kent Co.	James
Catl1	Whites Creek	Co Rte 679; Accomack Co.	Atlantic
Catl2	Untrib of Rangor Cr	off Co Rte 600; Northampton	Atlantic
Cpot3	trib of Dogue Cr	Rte 1; Fairfax Co.	Potomac
Rpot1	Potomac Creek	Co Rte 626; Stafford Co.	Potomac
Ryor1	Smoots Run	APHill; Caroline Co.	York
Rjam1	White Oak Swamp	Upstream of Rte 295; Henrico	James
Rrap1	Hazel Run	Co Rte 1299; Spotsylvania Co.	Rappahannock
Ryor2	Stevens Mill Run	Community Rd; Caroline Co.	York
Rpot2	Boars Creek	Co Rte 658; Stafford Co.	Potomac
Rrap2	Dragon Run	Co Rte 604; King 7 Queen Co.	Rappahannock
Rrap3	Totuskey Cr	Co Rte 619; Richmond Co.	Rappahannock
Rjam2	Crumps Swamp	Co Rte 665; New Kent Co.	James
Ratl1	Gargartha Cr	Co Rte 679; Accomack Co.	Atlantic
Ratl2	Taylors Cr	above Co Rte 600; Northampton Co.	Atlantic
Rpot3	Dogue Cr	Rte 611 & Kingman Rd; Fairfax	Potomac

Table 1(cont.). Final study sites for Phase II of hydromodification study.

Id No.	Stream	Location	Drainage
		Small-scale Dredge Sites	
890499	E. Br. Corrotoman R	Off Co rte 673; Lancaster Co.	Rappahannock
880899	Tuckahoe Cr	end of Gaskins Rd; Henrico Co.	James
891033	SBr. Elizabeth R	St Juliens Annex; Chesapeake	James
880102	trib of Broad Run	Rts 55 & 15; Prince William Co.	Potomac
950072	Four mile Cr	SW corner Wash. Natl. Airport; Alexandria	Potomac
960591	Nansemond R	Co. Rte 629 N, Suffolk	James
950748	Great Wicomico R	Off Co. Rte. 201/604; Northumberland Co.	Wicomico
880082	East River	Off Co. Rte 650; Matthews Co.	York
960114	Potomac R	End of Rte. 622; Westmoreland Co.	Potomac
911692	Rappahannock R	Moss Neck; King George Co.	Rappahannock
C0499	E. Br. Corrotoman R	2 river km upstream of Riverwood; Lancaster Co.	Rappahannock
C0899	Tuckahoe Cr	upstream of Gaskins Rd intersect; Henrico Co.	James
C1033	SBr. Elizabeth R	Upstream of experimental site; Chesapeake	James
C0102	trib of Broad Run	Co. Rte 682; Prince William Co.	Potomac
C0072	Henson Cr	upstream of Co. Re 210; Prince Georges Co., MD.	Potomac
C0591	Nansemond R	End of Co. Rte 706, Suffolk	James
C0748	Bush Mill Cr	Off Co. Rte. 201; Northumberland Co.	Wicomico
C0082	East River	Off Co. Rte 614; Matthews Co.	York
C0114	Potomac R	End of Rte. 622; Westmoreland Co.	Potomac
C1692	Rappahannock R	Moss Neck vicinity; King George Co.	Rappahannock

Table 2. Correlation coefficients of habitat variables with values for the first two axes from the canonical correspondence analysis on channelized sites and reference streams. Parentheses indicate cumulative percentage variance of site-habitat relation explained by the CCA. Dashes are used instead of numbers when a relationship is insignificant.

Environmental Variable	CCA 1 (27.1)	CCA2 (43.4)
Velocity	0.588	---
pH	0.360	---
Luse as forest	-0.328	-0.567
Luse as wetland	-0.308	-0.352
Luse as Agricultural	---	0.349
Turbidity	---	0.321

Table 3. Results of Independent Samples t-tests of habitat data from channelized (experimental group) and reference (control group). ** Indicates statistically significant differences between experimental and control groups ($P<0.05$).

Parameters	Units	Equal variance	Significance
Temperature	°C	Yes	0.72
Turbidity	NTU	Yes	0.45
pH		Yes	0.89
Dissolved oxygen	mg/L	Yes	0.79
Conductivity	μS/cm	Yes	0.98
Velocity	m/sec	Yes	0.51
Depth	meters	Yes	0.72
Width	meters	Yes	0.84
Riffle Habitat	Percent of 100 m	Yes	0.96
Run Habitat	Percent of 100 m	No	0.62
Pool Habitat	Percent of 100 m	No	0.64
Canopy	Percent of 100 m	Yes	0.02**
Cobble substrate	Percent of 100 m	Yes	0.76
Gravel Substrate	Percent of 100 m	Yes	0.57
Sand Substrate	Percent of 100 m	Yes	0.03**
Silt Substrate	Percent of 100 m	Yes	0.34
Clay Substrate	Percent of 100 m	No	0.10
Detritus Present	Percent of 100 m	No	0.58
Muck Present	Percent of 100 m	Yes	0.12
Marl present	Percent of 100 m	Yes	0.99
Epifaunal substrate	Scored over 100 m	Yes	0.02**
Pool substrate	Scored over 100 m	Yes	0.42
Pool variability	Scored over 100 m	Yes	0.15
Sediment Deposition	Scored over 100 m	Yes	0.43
Channel flow	Scored over 100 m	Yes	0.91
Channel alteration	Scored over 100 m	No	0.00**
Channel sinuosity	Scored over 100 m	No	0.02**
Bank stability (L)	Scored over 100 m	Yes	0.83
Bank stability (R)	Scored over 100 m	Yes	0.51
Bank vegetation (L)	Scored over 100 m	Yes	0.15
Bank vegetation (R)	Scored over 100 m	Yes	0.35
Riparian veg. (L)1	Scored over 100 m	No	0.052
Riparian veg. (R)	Scored over 100 m	No	0.10
Total Assess. Score	Calculated	Yes	0.025**

Table 4.. Correlation coefficients of habitat variables with values for the first two axes from the canonical correspondence analysis on dredged sites and reference streams. Parentheses indicate cumulative percentage variance of site-habitat relation explained by the CCA. Dashes are used instead of numbers when a relationship is insignificant.

Environmental Variable	CCA 1 (56.4)	CCA2 (85.9)
Luse as Agricultural	0.852	---
Link values	0.843	-0.523
Turbidity	-0.840	-0.457
Depth	-0.442	-0.553
Luse as residential	-0.344	---
Luse as wetland	---	0.516
Dissolved Oxygen	---	0.311
Stream width	---	-0.812
Luse as forest	---	-0.415

Table 5. Results of Independent Samples t-tests of habitat data from dredged (experimental group) and reference (control group). ** Indicates statistically significant differences between experimental and control groups (P<0.05).

Parameters	Units	Equal variance	Significance
Temperature	°C	Yes	0.97
Turbidity	NTU	No	0.20
pH		Yes	0.46
Dissolved oxygen	mg/L	Yes	0.91
Conductivity	μS/cm	Yes	0.99
Velocity	m/sec	Yes	0.98
Depth	meters	Yes	0.69
Width	meters	Yes	0.90
Riffle Habitat	Percent of 100 m	Yes	0.67
Run Habitat	Percent of 100 m	Yes	0.82
Pool Habitat	Percent of 100 m	Yes	0.93
Canopy	Percent of 100 m	Yes	0.17
Cobble substrate	Percent of 100 m	Yes	1.0
Gravel Substrate	Percent of 100 m	Yes	1.0
Sand Substrate	Percent of 100 m	Yes	0.20
Silt Substrate	Percent of 100 m	Yes	0.20
Clay Substrate	Percent of 100 m	Yes	0.41
Detritus Present	Percent of 100 m	Yes	0.09
Muck Present	Percent of 100 m	Yes	0.10
Marl present	Percent of 100 m	Yes	0.84
Epifaunal substrate	Scored over 100 m	Yes	0.02**
Pool substrate	Scored over 100 m	Yes	0.58
Pool variability	Scored over 100 m	Yes	0.12
Sediment Deposition	Scored over 100 m	Yes	0.57
Channel flow	Scored over 100 m	Yes	0.51
Channel alteration	Scored over 100 m	Yes	0.04**
Channel sinuosity	Scored over 100 m	Yes	0.89
Bank stability (L)	Scored over 100 m	Yes	0.03**
Bank stability (R)	Scored over 100 m	Yes	0.13
Bank vegetation (L)	Scored over 100 m	Yes	0.04**
Bank vegetation (R)	Scored over 100 m	Yes	0.13
Riparian veg. (L)1	Scored over 100 m	Yes	0.10
Riparian veg. (R)	Scored over 100 m	Yes	0.04**
Total Assess. Score	Calculated	Yes	0.004**

Figure 1. Sample Rapid Habitat Assessment Data Sheet used to evaluate instream and riparian habitat conditions.

Figure 2. Additional Field Habitat Assessment Data Sheets used for the evaluation of habitat conditions.

Figure 3. First and second axes from the canonical correspondence analysis of sites and habitat parameters from channelized and reference streams of the Coastal Zone Management Area, Virginia. Dots represent sites. See Table 1 for code descriptions.

Figure 4. First and second axes from the canonical correspondence analysis of sites and habitat parameters from channelized and reference streams of the Coastal Zone Management Area, Virginia. Vectors represent habitat variables; symbols represent nominal landuse types.

Figure 5. First and second axes biplot from the canonical correspondence analysis of sites and habitat parameters from channelized and reference streams of the Coastal Zone Management Area, Virginia. Dots represent sites. Vectors represent habitat variables; symbols represent nominal landuse types.

Figure 6. First and second axes from the canonical correspondence analysis of sites and habitat parameters from small-scale dredging operations and reference streams of the Coastal Zone Management Area, Virginia. Dots represent sites. See Table 1 for code descriptions.

Figure 7. First and second axes from the canonical correspondence analysis of sites and habitat parameters from small-scale dredging operations and reference streams of the Coastal Zone Management Area, Virginia. Vectors represent habitat variables; symbols represent nominal landuse types.

Figure 8. First and second axes biplot from the canonical correspondence analysis of sites and habitat parameters from small-scale dredging operations and reference streams of the Coastal Zone Management Area, Virginia. Dots represent sites. Vectors represent habitat variables; symbols represent nominal landuse types.

Appendix I. Chapter 5 of Barbour et al. 1999. Description of methodology for rapid habitat assessment.

Appendix II. McIninch, S.P. and G.C. Garman. 2000. Identification and analysis of aquatic and riparian habitat impairment associated with dams of the Virginia Tidewater region. Final Project Report to Virginia Department of Conservation & Recreation, Richmond, VA.